Upper Yellowstone River Hydrogeomorphic Functional Assessment for Temporal and Synoptic Cumulative Impact Analyses

INTRODUCTION: Until recently, methods of evaluating wetland loss or degradation were either so generalized that detection of change was not quanitifiable or required exhaustive research beyond the human or finanacial resource scope of a regulatory program. The hydrogeomorphic (HGM) approach to the functional assessment of wetlands was specifically developed, principally by the U.S. Army Corps of Engineers and other Federal and state agencies throughout the United States, as a comprehensive framework for rapid evaluation of wetland ecosystem function (Smith et al. 1995). The HGM approach is implemented at the local or regional level through the identification of a series of functions performed by the wetland subclass, followed by development of regional guidebooks containing logic models that represent the functions. The logic models are composed of variables that degrade correlatively with level of human impact and play a vital role in the function described by the model. The output of each model is an index scaled from 0 to 1.0, where 0 represents a completely altered condition such that the function no longer occurs and 1.0 represents the unaltered, naturally occurring level of function. Thus, the functional capacity index (FCI) scores of subject wetlands are based on a reference data set that captures the range of variation of impact for the regional subclass.

In summary, the HGM approach accomplishes the following:

- Wetlands are classified in a way that permits the aggregation of similarly functioning wetlands.
- Data from a reference or "calibration" data set capture the range of variation of specific attributes that characterize function.
- A multivariate approach evaluates and scales the attributes of the scope of reference conditions from least impacted to severely impacted.
- A multi-metric approach evaluates cross-wetland comparison of function-specific performance that is expressed as a series of FCIs (Hauer and Smith 1998). Thus, the FCI's for each function are readily used to evaluate impacts, compare project alternatives, or help design and evaluate mitigation plans on a project-by-project basis.

A criterion that must be considered in conjunction with measuring ecological change for programmatic needs is the capacity of a wetland to perform functions in relation to some standard of comparison. The HGM approach provides for reference-based comparitive analyses. Additionally, the original design of the HGM approach was to assess how a wetland relates to its surrounding ecosystem and focuses on conventional impact assessment at a site scale. Smith et al. (1995) discuss the limitations of the HGM approach for this spatial scale of impact analysis. Among the limitations they discuss is the fact that the functional indices developed under this approach cannot be used to assess the cumulative impacts of a proposed project, as required by the Clean Water Act's public interest review process (33 CFR Section 320.4 (a) (3)). In assessing cumulative impacts, the focus shifts from the functions performed at the wetland ecosystem scale to the larger landscape or watershed scale. Also, the scope of analysis in cumulative impact assessments is generally larger with respect to the number and types of disturbances, the geographic area, and time frame considered

rather than with traditional project-based assessments (Bedford 1999). HGM guidebooks developed since Smith et al. (1995) have, however, included landscape-scale metrics for both variables and FCI's. The landscape metrics may therefore provide reference-based comparative analysis at larger spatial scales.

Johnston (1994) stated that loss of wetlands could result in a corresponding loss of "cumulative wetland function" at the landscape scale. Bedford and Preston (1988) recognized the incongruity between the regional and national scales at which wetland losses occur and the project–specific scale at which wetlands are regulated and studied. These authors argued that the appropriate scale for cumulative impact assessment should be that of interacting systems of wetlands located within watersheds, landscapes, and regions. Clark (1986) argued that cumulative impact assessment needs a "synoptic approach" so that all potentially significant impacts are considered. Abbruzzese and Leibowitz (1997) further developed the synoptic approach in cumulative impact assessment using landscape indicators for regional prioritization needs. These authors did caution that the utility of the synoptic assessment approach depends on how well knowledge of the environment is incorporated into assessment needs relative to the management question. Given that wetlands are functionally interdependent on the landscape (Bedford and Preston 1988, Mitsch and Gosselink 1993), cumulative effects analyses need to draw attention to riparian/wetland mosaics as landscape units so that decision makers can more effectively evaluate individual mitigation decisions in the context of broad-scale patterns of diversity (Bedford 1996). In her discussion of cumulative effects on wetland landscapes and the linkages to wetland restoration, Bedford (1999) introduced the concept of templates for wetland restoration. These templates are based on landscape profiles documenting hydrologic, geologic, and climatic interactions within the context of the hydrogeomorphic classification concepts of Brinson (1993) for evaluation of past and present conditions. These concepts do not specifically address programmatic needs to project conditions in restoration efforts or development of thresholds for significance in cumulative impact analyses, but could likely be used in this regard.

The above discussion illustrates scientific and pragmatic concerns regarding methods for cumulative impact assessment. Development of the appropriate temporal–spatial scales for analyses, defining interrelationships between scales, developing significance thresholds of impacts, and projecting future conditions should all be well-defined by the nature of the systems being assessed and then placed within an appropriate management context. Within a practical perspective, the scope of analyses for a given management question will likely be defined within a context limited by available technical methods, statutory requirements, funding, and in consideration of public interest factors specific to assessment needs.

Application of the HGM approach to cumulative impact assessment using landscape-level metrics in conjunction with traditional site-scale metrics in HGM guidebooks has not been tested. Extension of the reference site concept inherent to HGM (Brinson and Rheinhardt 1996) to a "reference landscape" or "landscape assessment area" may allow for the temporal and spatial comparisons implicit within cumulative effect analysis. Further, site-specific scale analyses, more directly related to an agency's authority or management needs, can still be maintained within the context of HGM guidebooks.

The ecology of western riparian/floodplain systems explicitly requires a more expanded scale of analysis for any cumulative impact assessment or, for that matter, any "project-specific" perturbations. Physical, chemical, and biological patterns and processes in river networks are structurally and functionally linked and operate across a hierarchy of spatio-temporal scales (Frissell et al. 1986, Minshall 1988). At the landscape scale, the river network is intimately linked to longitudinal gradients (Vannote et al. 1980), riparian vegetation, and processes in and around wetlands (Gregory et al. 1991), and surface-subsurface water exchange (Stanford and Ward 1993, Jones and Mulholland 1999, Baxter and Hauer 2000). The HGM guidebook developed for western riparian systems emphasizes these landscape-scale processes, as well as the processes that tend to be site-specific.

In 1997, in conjunction with the Flathead Lake Biological Station of the University of Montana, the U.S. Army Engineer Waterways Experiment Station and the Omaha District Office initiated the development of the HGM approach to functional assessment for riparian floodplains in the Northern Rocky Mountains (NRM). The draft guidebook "The Hydrogeomorphic Approach to Functional Assessment: A Regional Guidebook for Assessing the Functions of Riverine Floodplain Wetlands in the Northern Rocky Mountains" by Hauer et al. (in preparation) was used as the basis for this case study.

YELLOWSTONE RIVER – CASE STUDY: Flooding of the Yellowstone River in 1996 and 1997 caused extensive cut-and-fill alluviation, a redistribution of coarse river sediment, and reworking of the Yellowstone River floodplains between Gardiner and Livingston, Montana. Cut-and-fill alluviation of the river channel, flooding of the river floodplain, and threat of recapture of floodplain spring brooks resulted in private property losses. Private land owners responded with increased Section 10/404 permit requests for bank stabilization activities.

In addition to being the longest unregulated river in the conterminous 48 states, the Yellowstone River provides a plethora of ecological "goods and services" (e.g., Costanza, Daly, and Bartholomew (1991)) that make this river a critical resource for Montana, and indeed the entire United States. Given the resource significance of this area, maintaining the quality of the Yellowstone River system in the face of these recent changes has been a concern of federal and state agencies, as well as the general public.

The Corps of Engineers' institutional response to the increase in permit activity has been to initiate the development of a Special Area Management Plan (SAMP) in concert with interagency partners and the local community. A SAMP is a regulatory planning tool for the Corps to administer its permit program in consideration of corridor or watershed concerns and objectives as opposed to the traditional case-by-case individual permit review. For the upper Yellowstone River SAMP, a scope of analysis, cumulative impacts, evaluation of alternatives for river corridor planning, and development of a consensus-based river management strategy are included. To support a river corridor plan, modification to the permitting process is anticipated. Those actions that significantly impact river/floodplain functions, either individually or incrementally, may be restricted or prohibited. General permits may be developed for those actions found to have insignificant impacts (both individually and cumulatively).

Baseline studies for the SAMP have been directed toward channel hydraulics and geomorphology, cottonwood recruitment, fisheries, and engineering/natural resource mapping. Although these

studies provide individual metrics and supporting data, they do not provide a broad perspective or provide for either functional assessment of the river floodplain mosaic or for interdisciplinary integration and development of cumulative impact assessment and alternative analyses. Additionally, prior to this study, the temporal comparisons required for cumulative impact assessment and alternative analyses have not been adequately defined for river corridor planning. Herein, we present the results of an HGM functional assessment of selected floodplain reaches of the upper Yellowstone River using the Northern Rocky Mountain Riverine HGM Guidebook (Hauer et al., in preparation). Specifically, this case study is intended to address the following:

- The range of variation in functional capacity for selected functions under current conditions within the study corridor.
- Reconstruct, through synoptic means, past conditions expressed in terms of FCI.
- Directly compare current and historic conditions to future condition scenarios for the corridor.
- Discuss these results in the context of other reference sites under the assumption that time is subsumed in the reference data set.

These analyses may help define future SAMP study needs and provide insight toward understanding cumulative impacts and refining alternative analyses.

METHODS

Study Area. River drainage networks throughout the Rocky Mountains are an integral part of the landscape mosaic that forms regional patterns of topography, geochemistry, vegetation, and the bio-physical processes that provide the template for ordering biological systems; including the distribution and forms of wetlands on floodplain surfaces (sensu Stanford (1998)). The upper Yellowstone River is contained within the Reference Domain of the Northern Rocky Mountain Riverine HGM Guidebook (Hauer et al., in preparation) (Figure 1).

The HGM functional assessment was conducted on three river reaches between Emigrant and Livingston (Figure 1). Nine Assessment Areas were selected for study within the river reaches; four from the Spring Creek reach, two from the Mallard's Rest reach, and three from the Emigrant reach. The spatial extent of the study floodplain assessment areas ranged from 7.3 to 28.2 ha. The Emigrant to Livingston segment of the river was selected based on the high frequency of Section 10/404 permit requests for bank stabilization activities that have occurred there since the flooding of 1996-97. Assessment areas were sited only within floodplains where cut-and-fill alluviation has been particularly active, generating permitting actions such as the construction of bank stabilization structures (e.g., rock barbs, rip-rap) or dikes to restrict river flow.

Field Work. The field portion of this study was conducted during mid-September 2000. Two teams of field researchers with extensive experience in the development of the riverine HGM functional assessment procedures conducted the synoptic studies and collected all field data. All data were collected within the guidelines detailed in the Northern Rocky Mountain Riverine HGM Guidebook (Hauer et al., in preparation). The variable data collected are summarized in Table 1. Field teams cross-referenced their data collections and communicated prior to and immediately following the collection of data on each assessment area to ensure consistency and accuracy of the data being collected.

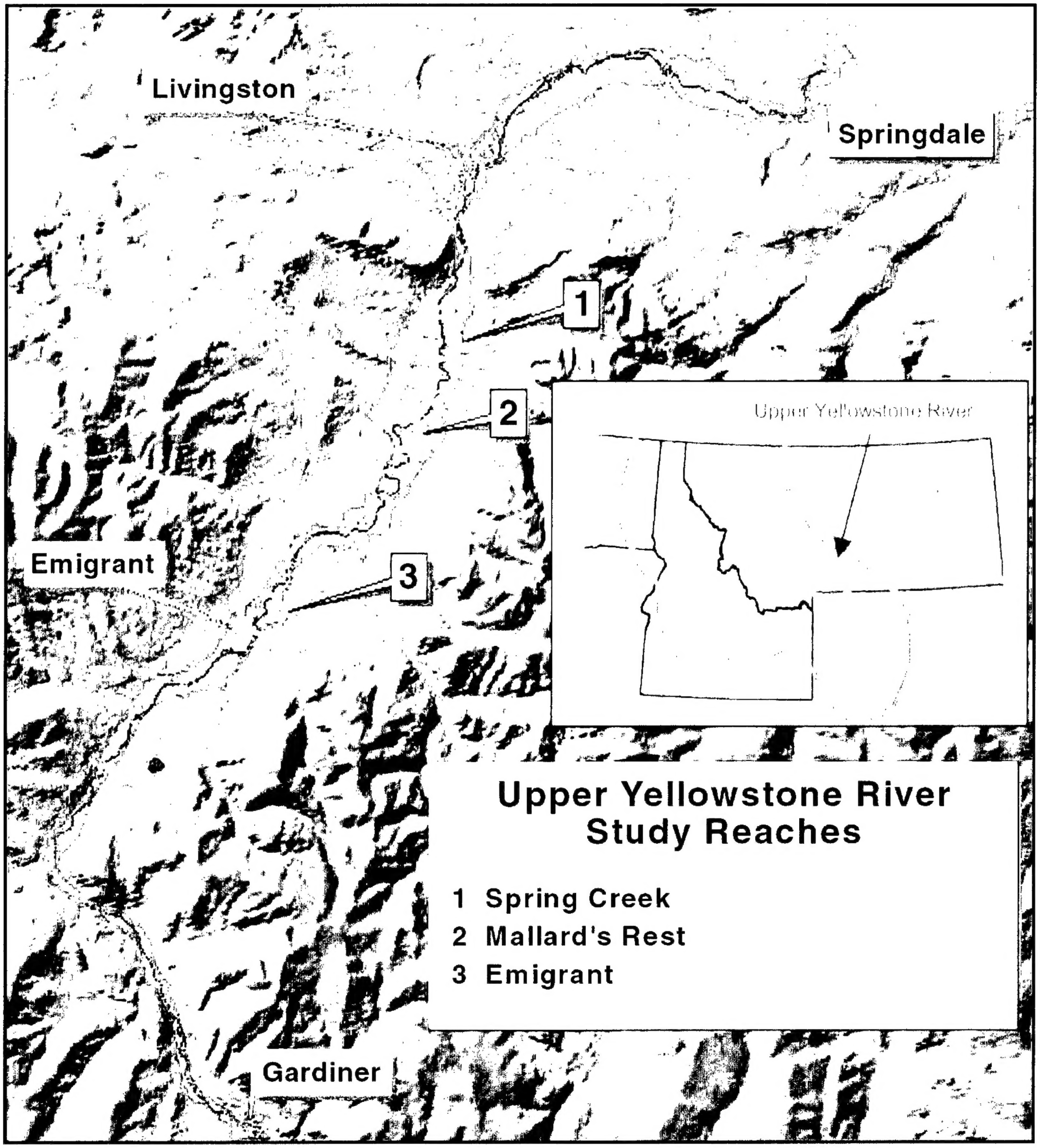

Figure 1. Color topograpic map of the upper Yellowstone River between Gardiner and Livingston, Montana. Inset map illustrates the upper Yellowstone River within the reference domain of the HGM functional assessment sub-class. The red line extending down the valley marks the general extent of riparian influence along the river, indicated in blue. The green circles, labeled 1, 2, and 3, indicate the three study floodplain segments

Table 1
List of Variables Collected from Field and Landscape Data

$V_{COMPLEX}$	Proportionality of landscape features
V_{HABCON}	Floodplain habitat connectivity
V_{GEOMOD}	Geomorphic modifications affecting hydrologic flow
$V_{LANDUSE}$	Proportional land use within the assessment area
V_{MACRO}	Macrotopographic complexity
$V_{SURFREQ}$	Frequency of overbank flooding
$V_{SUBFREQ}$	Frequency of flooding from subsurface input
$V_{ORGDECOMP}$	Microbial decomposition of organic matter
V_{DTREE}	Tree density
V_{SHRUB}	Shrub and sapling density
V_{HERB}	Herbaceous plant density
V_{LWD}	Large wood debris
V_{NPCOV}	Percent coverage of native plants

Field Data, Variable Subindex Scores, and Functional Capacity Index Scores. Each cover type occurring in a study assessment area was sampled. Sample data were then compared with the reference data set (Hauer et al., in preparation). Based on these comparisons, each variable listed in Table 1 was assigned a variable subindex score by cover type. Variable subindex scores from each cover-type polygon were applied proportionally by area resulting in an overall assessment area subindex score for each variable. Subindex scores for each variable within each assessment area were applied to the functional capacity models of the Guidebook (Hauer et al., in preparation) to provide a functional capacity index score for each of eight functions described for the riverine wetland subclass (Table 2). Algorithms for each function are described in Appendix A.

The variables V_{GEOMOD}, $V_{COMPLEX}$, V_{HABCON}, and $V_{LANDUSE}$ were found to be most directly affected by human impact in the study area. Each of these variables either manifest at the landscape spatial scale, or are strong interactors with other variables. Each of these variables were scaled on narrative criteria (Hauer et al., in preparation), which are summarized by variable in Appendix B.

Synoptic Analyses. Aerial color infrared photography dated September 25, 1997, was provided by the Corps' Omaha District Office and served as the basis for analysis of the current condition. These 1:12000 photos were scanned at 600 pixels per inch. Photographs containing the assessment areas were brought into a GIS environment (ArcView and ArcInfo, ESRI 2000) and digitized to delineate the boundaries of each cover type within the assessment areas. Cover types within the assessment areas were determined and delineated on heads-up display based on a combination of: (a) type-verification conducted during the field data collection, and (b) identification of cover type determined on the photographs. Field data were then applied to each of the cover types within each assessment area on a percent area occupied by each cover type polygon. Geomorphic modifications (V_{GEOMOD}) to the river and floodplains affecting each assessment area were determined by examination of the 1997 CIR photographs and a physical features inventory (PFI) GIS coverage and database maintained at the Omaha District's Office. Physical features were transferred to the

Table 2
List of Functions for the Northern Rocky Mountain Riverine HGM Guidebook (Hauer et al., in preparation) and Applied in This Study to Each of the Nine Assessment Areas of the Upper Yellowstone River

Function 1	Surface Water – Groundwater Storage and Flux
Function 2	Nutrient Cycling
Function 3	Retention of Organic and Inorganic Particles
Function 4	Generation and Export of Organic Carbon
Function 5	Characteristic Plant Community
Function 6	Characteristic Aquatic Invertebrate Food Webs
Function 7	Characteristic Vertebrate Habitats
Function 8	Floodplain Interspersion and Connectivity

registered CIR photographs and determination of effects were scored, based on structure position, magnitude, and type of structure. These data were also compared to black and white aerial photographs (1:24,000) taken September 28, 1976. Landscape features from the 1997 and 1976 photographs were used in subsequent analyses to evaluate change in floodplain function over time.

Temporal Analyses: Cumulative Impact Assessment and Alternative Analyses. Based on the site data collected in 2000, the landscape data determined from the CIR 1997 photographs, and the physical features inventory coverage, the variable subindex scores of each variable were determined, which then permitted determination of functional capacity index scores for each function within each assessment area. Probable functional capacity conditions for 1976 were also determined. The "backcast condition" for each assessment area was based on a comparison of stereo photo-interpretation of the 1976 photos to the physical features inventory database. This comparison determined which bank stabilization structures were present in this time frame. An assumption of similar land use and site variable response to the contemporary condition was used in calculating FCIs.

Variable subindex scores and FCIs for two potential future scenarios were also estimated. Evaluations of geomorphic modification (V_{GEOMOD}) and land use ($V_{LANDUSE}$) were the principal impact drivers in these scenarios. Scoring of the probable response of other variables to changes in V_{GEOMOD} and $V_{LANDUSE}$ was based upon extrapolation from the reference data set, as a documented range of variation, and concurrence of the assessment team.

The first scenario was based on reduction of existing river bank and floodplain geomorphic modifications to the 1976 condition plus incorporation of resource management directed toward native vegetation coverage and diversity. This scenario involved a change from winter-intensive grazing to less intense grazing and is referred to as forecast-unconfined. The second scenario was based on maintaining all existing stabilization structures, plus placement of bank stabilization structures at all sites identified in the physical features inventory as having unstable banks. The second scenario also included a single residential development onto each of the assessment areas, which was based on the observation that bank stabilization and levees can lead to residential encroachment into the floodplain. This second scenario is referred to as forecast-confined.

The four-way comparison (current condition, backcast condition, forecast-unconfined, and forecast-confined) facilitates functional assessment of the river floodplain mosaic for integration and development of cumulative impact assessment (CIA) and alternative analyses (AA). By sampling nine assessment areas across three river floodplain reaches, the distribution and extent of impact to floodplain function resulting principally from placement of various flow-confining structures and land use were evaluated. Collectively, comparison of these HGM functional assessments between sites and between current and backcast conditions are one form of cumulative impact assessment. Application of this approach to the two future scenarios, likewise, is a form of alternative analysis.

Context with the Reference Data Set. Five floodplains from the reference data set used to calibrate the Northern Rocky Mountain riverine HGM guidebook were selected (Hauer et al., in preparation) for direct comparison with the four time periods of analysis. The reference floodplains for this comparison range in functional index scores from floodplains approaching the reference standard condition to a river floodplain that has been severely impacted by human activities. Comparisons were made across all functions comprised of the mean FCIs of the upper Yellowstone River assessment areas for each time frame (i.e., current, backcast, forecast-unconfined, and forecast-confined). The range of functioning implicit in the reference data set gave a context from which to evaluate the potential temporal trajectories in functional capacity of the Yellowstone River assessment areas.

RESULTS

Aerial Photographs and Physical Structures Inventory. Data on stabilization structures and sites of eroding and unstable river banks were developed from the physical features inventory (PFI) coverage (Table 3). Current and backcast structures including type and location were determined and placed onto the 1997 aerial color infrared photographs (current condition) and the 1976 black and white aerial photographs (backcast condition) to assist in scoring the geomorphic and landscape variables for each assessment area (Figure 2). Structures and eroding banks for each area were evaluated extending 800 m (~0.5 mile) above and below each floodplain assessment area. These data clearly show the increase in the frequency of rock barbs and jetties. However, the most pervasive structure development across the three study reaches of the river floodplains has been in the use of rock riprap, which increased from a total of 1,032 m in 1976 to 2,212 m by 2000. The frequency and distribution of dikes also increased dramatically in the Spring Creek Reach, increasing by over 500 percent between 1976 and 2000.

Functional Capacity Indices among Yellowstone River Assessment Areas. The subindex scores by variable and the functional capacity index scores by function for each assessment area and each of the four temporal scenarios (i.e., current condition, backcast condition, forecast-unconfined, and forecast-confined) are summarized in Appendix C and Appendix D, respectively.

Considerable variation was observed in FCI scores among all functions between study floodplain reaches and between assessment areas within reaches. However, because the type of human activities in the study reaches of the Yellowstone River have been the placement of river bank structures and floodplain diking, as well as grazing land uses, the greatest changes between 1976 and 2000 were associated with the variables affecting Function 1 (Surface Water – Groundwater

Table 3
Summary of Structures and Eroding Banks in the Emigrant, Mallard's Rest, and Spring Creek Reaches of the Upper Yellowstone River in 2000 and 1976*

Area/WAA	Rock Barb	Rock Jetty	Rock Riprap	Dike	Eroding Bank
			2000		
Emigrant Reach	—	3	489	—	2722
Mallard's Rest Reach	14	—	531	—	62
Spring Creek Reach	17	6	1192	1698	3567
			1976		
Emigrant Reach	—	—	96	—	—
Mallard's Rest Reach	—	—	—	—	—
Spring Creek Reach	14	4	938	336	—

* Rock barbs and rock jetties are given as frequency of occurrence; rock rip-rap, dikes, and eroding banks are presented in meters of length.

Storage and Flux), Function 5 (Characteristic Plant Community), and Function 8 (Floodplain Interspersion and Connectivity) (Figure 3).

Comparisons across reaches and temporal conditions within Function 1 show that there has been relatively small change in function of floodplain surface water and groundwater storage and flux between 1976 (backcast) and 2000 (current) at the Emigrant or Mallard's Rest reaches. However, there was an approximately 0.2 FCI decline during this time interval among the assessment areas of the Spring Creek reach. This can be largely attributed to the increased frequency and length of dikes within that reach. The forecast-unconfined future scenario redefined the characteristics of this function to result in an increase in FCI scores for all reaches, although the greatest increase was observed at the Spring Creek reach. In contrast, the forecast-confined future scenario observed significant decline in FCI scores for all three reaches.

Function 5, which assesses the environmental condition of the plant community, revealed that the riparian vegetation among these reaches has declined significantly from the assumed 1976 conditions. This was most pronounced at the Mallard's Rest reach, where we measured heavy grazing pressure on Assessment Area 1 (east) as well as significant impacts on vegetation in Assessment Area 2 (west), as a result of the campground/river access. The forecast-unconfined and forecast-confined scenarios resulted in uniform increases or decreases of function, respectively. However, the decrease in function due to river confinement did not affect Function 5 as dramatically, as was observed in Function 1. This is largely due to the substantial impacts to the ecological integrity of the vegetation communities that had already occurred in this reach as the result of grazing and recreational land use practices.

Function 8 describes interconnectivity of floodplain habitats. This function has been most significantly affected at the Spring Creek reach between 1976 and 2000, where there has been a decrease in function at Assessment Areas 2, 3, and 4 (see Figure 2 and Appendix D) of more than 0.2 FCI units. Improvement in function is observed in the forecast-unconfined scenario, particularly among these same assessment areas. However, the forecast-confined scenario is characterized by dramatic decrease in function across all reaches (Figure 3).

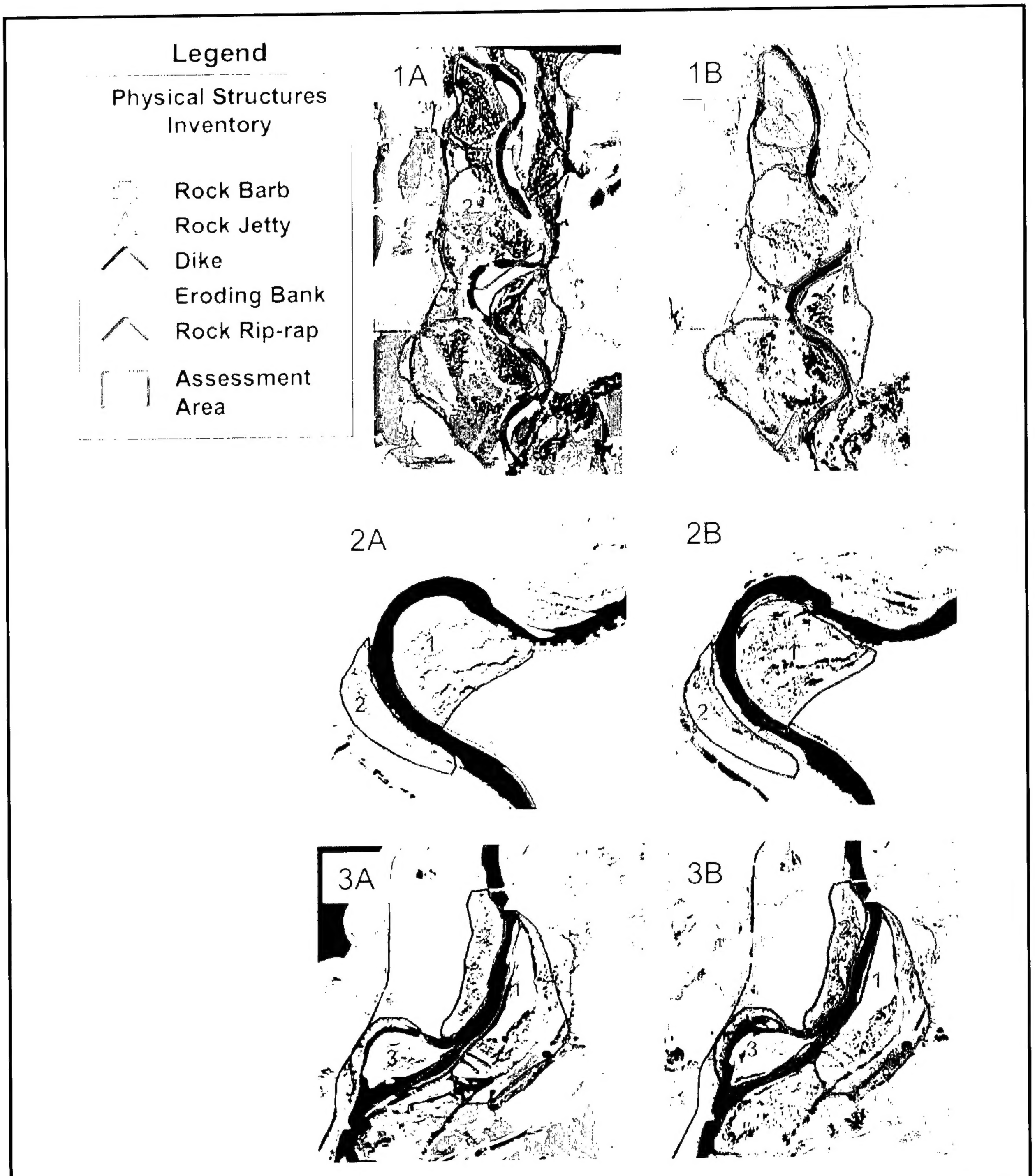

Figure 2. Assessment areas within the three study river floodplain segments of the upper Yellowstone River; Panels: 1-Spring Creek, 2-Mallard's Rest, 3-Emigrant. A is composed of the 1997 aerial photos and the 2000 Physical Features Inventory (current condition). B is the 1976 black and white aerial photos and the 1976 PFI (backcast condition). Assessment areas (blue) within each river floodplain segment are numbered

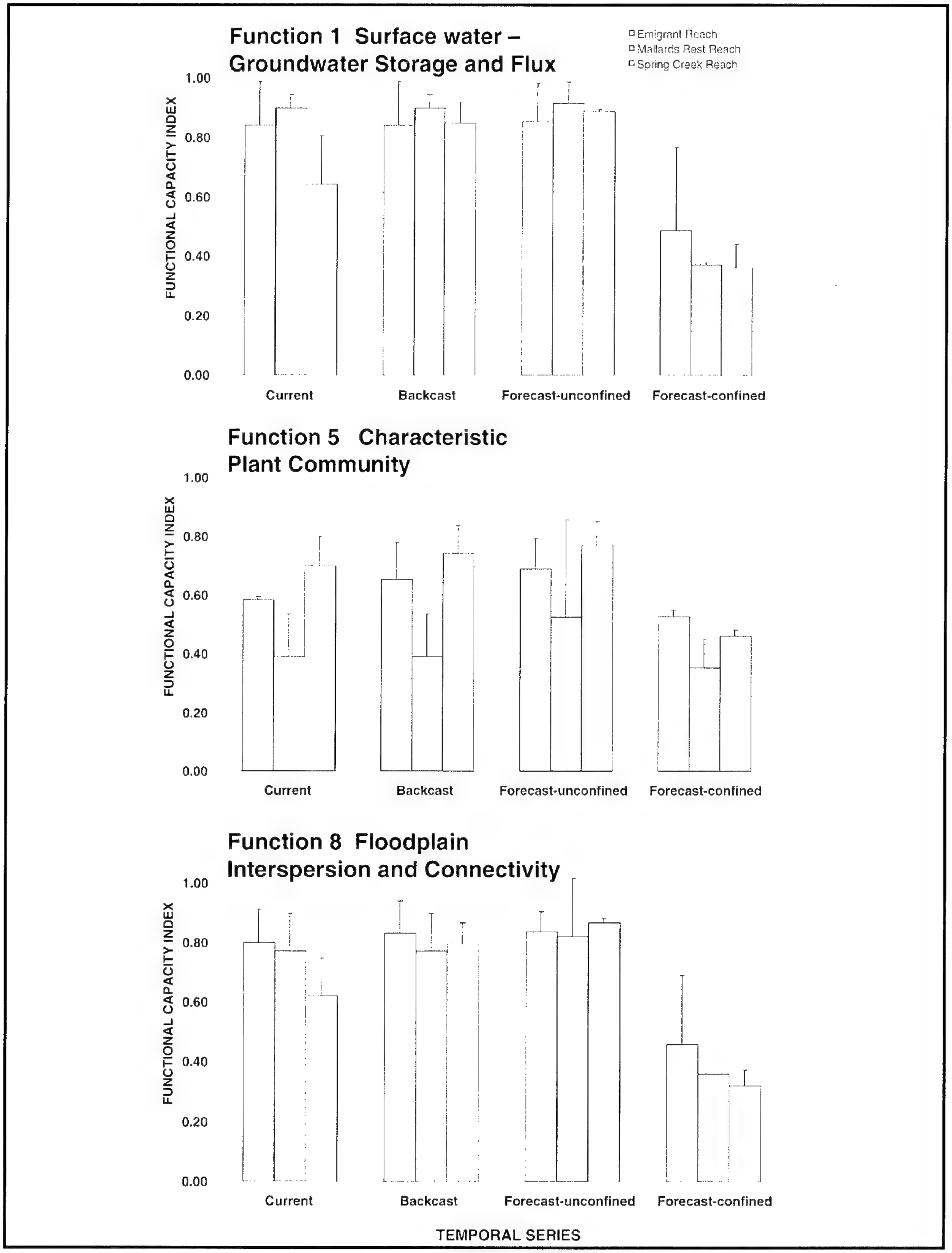

Figure 3. Functional capacity indices of Functions 1, 5, and 8 for each of four temporal conditions/scenarios across the three study reaches. Bars indicate assessment area means ± S.E.

Comparison of the Yellowstone River Floodplains to Other Regional Floodplains. Mean FCI scores across all assessment areas combined among the upper Yellowstone River Reaches were compared to the FCI scores from selected river floodplain reaches within the reference domain. The reference floodplain reaches that comprised the reference data for the HGM guidebook (Hauer et al., in preparation) range from very high-rated function to very low. The mean FCI scores among the Yellowstone River assessment areas were much lower than the near-pristine example floodplain on the Middle Fork of the Flathead River in NW Montana (Figure 4). The Yellowstone River FCI scores were very similar to those of the upper Snake River near Jackson, where there have also been significant effects on the floodplains as a result of geomorphic modifications, grazing, planting of exotic grasses, and invasions of nonnative species within the herbaceous plant community. The Yellowstone River also scored similarly to the Clark Fork River at the Grant – Kohrs Ranch, which has experienced a long history of grazing and invasions of nonnative herbaceous plants, but has not had as much geomorphic modification and bank stabilization as the Yellowstone River. The river floodplain that had the lowest FCI scores among the suite of comparison floodplain reaches was the Clark Fork River at Missoula, which is extensively modified by riprap, dikes, and levees and is uniformly lower in function than the current condition on the Yellowstone River. However, mean FCI scores across all functions on the Yellowstone River assessment areas for the forecast-confined scenario approached those of the Clark Fork River at Missoula.

DISCUSSION: Nine assessment areas on the upper Yellowstone River were analyzed using the HGM approach to functional assessment found in the Northern Rocky Mountain Riverine HGM Guidebook (Hauer et al., in preparation). Functional capacity index scores for the current condition were developed based on field data collected during autumn 2000, landscape data based on 1997 CIR photographs, a physical features inventory (PFI), and field verifications. The current condition FCI scores were compared to estimated FCI scores for a backcast condition based on likely variable responses to 1976 land use, a 1976 aerial photographic series, and the PFI database.

FCI scores for two future-cast scenarios were also estimated, one that was based on removing the geomorphic modifications that restrict or "confine" the river and prevent flooding onto the floodplain. This scenario included changing land use management toward native vegetation coverage and diversity; this scenario is referred to as forecast-unconfined. The other future-cast scenario involved adding geomorphic modification and bank stabilization at all locations that the PFI database indicated as riverbanks experiencing instability and erosion by the river. This scenario included land use practices with increased human encroachment into the floodplain. This scenario is referred to as forecast-confined.

Current mean FCI scores of the upper Yellowstone River were also compared with the FCI scores from five reference river-floodplain complexes in the reference domain. The inter-river comparisons directly place the four management scenarios of the upper Yellowstone River floodplains into a broader context of the region and a potential temporal trajectory as compared to the reference floodplains.

Results of this study showed significant decline in FCI scores in the upper Yellowstone River floodplain assessment areas between 1976 (backcast condition) and 2000 (current condition). Declines were focused spatially in four assessment areas: Emigrant 1 and Spring Creek 2, 3, and 4. These declines are attributable to addition of riverbank and floodplain stabilization structures over

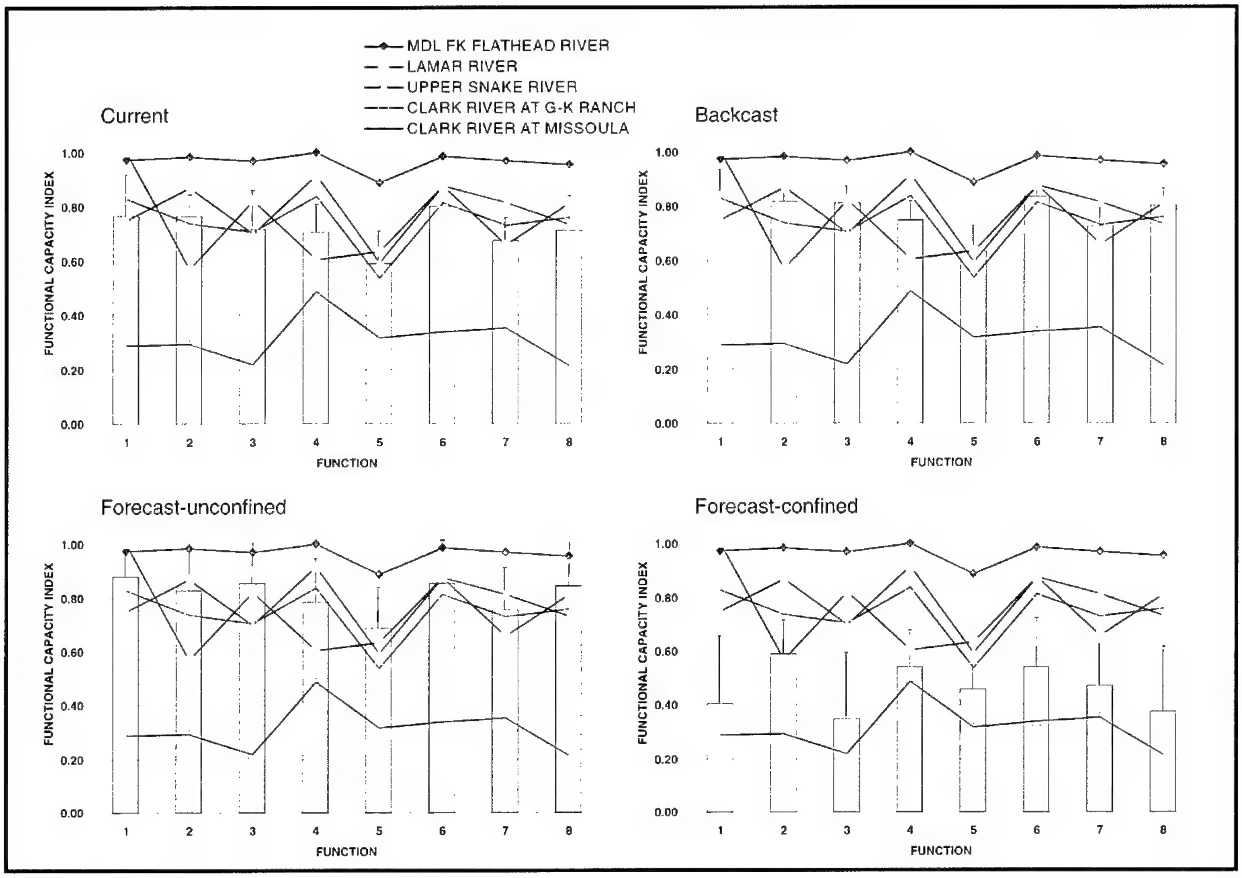

Figure 4. Functional capacity index scores across all functions. Bar graphs are the mean FCI scores (± S.E.) of the Yellowstone River assessment areas. Line graphs indicate FCI scores of a suite of comparative floodplains within the reference domain

the 25-year period at those assessment areas. The ecological integrity of the riparian vegetation has also been affected among the study floodplains. This is reflected by the depressed FCI scores of Function 5, particularly in the Mallard's Rest Reach. This is unlikely to change significantly on the west side of the river (Mallard's Rest 2), where there is a large campground and river access.

The two future scenarios evaluated herein produced distinctly different potential functional responses, as reflected in the FCI scores. FCI scores increased uniformly across all functions in the forecast-unconfined scenario. This response was principally the result of higher variable subindex scores projected for the variables V_{GEOMOD}, $V_{SURFREQ}$, and $V_{SUBFREQ}$ (refer to Appendix C) as a direct result of increased linkages of flow and maintaining of an interspersed floodplain associated with riprap and dike removal. FCI scores also were projected to increase because of anticipated response of vegetation to a new land use practice directed toward native plant communities through prescribed grazing management. In contrast, FCI scores decreased uniformly across all functions in the forecast-confined scenario as projected variable subindex scores decline as riverbank and floodplain structures increase in frequency and dimension.

The cumulative impact to the upper Yellowstone floodplains of developing riverbank and floodplain "protective" structures, land use practices and invasion of nonnative vegetation is clearly demonstrated by the HGM approach to functional assessment. The 1976 (backcast) condition already

demonstrated some loss of function as a result of land use (principally grazing) and minimal riprap and diking, as a departure from the natural, fully functioning condition. Loss of function between 1976 and 2000 was primarily attributable to the proliferation of bank and floodplain structures to prevent localized erosion or channel avulsion. By evaluating the floodplains across a series of floodplain assessment areas taken from a broad spatial extent, we were able to evaluate the distribution and accumulation of human impact across the landscape of river floodplains of the upper Yellowstone River. Clearly, the impact has been spatially extensive and has affected a full array of floodplain functions. As stated by De Leo and Levin (1997), it is the dynamic processes themselves that guarantee the functioning of an ecosystem, and any effort to constrain natural variability will eventually lead to self-simplification and fragility of the system.

Two very disparate future management alternatives were examined; a best-case and a worst-case scenario for alternative analyses. One future case evaluated the probable functional response to removal of structures and changing land use management toward native diversity and coverage. In this scenario, the forecast-unconfined, a uniform increase in FCI was observed across all functions. This is compared to the forecast-confined scenario that has unstable banks riprapped and diked. In this later scenario, a dramatic decline in floodplain function was observed across all river reaches.

These observations and projections, based on the HGM approach to functional assessment, were given further credence by comparison between the upper Yellowstone River floodplains and the reference data-set from the Guidebook reference domain (Hauer et al., in preparation). These comparisons revealed that the upper Yellowstone River functional capacity is similar to other rivers in the Northern Rocky Mountain region that have experienced placement of stabilization structures, grazing pressure, and other consequences of human encroachment. By direct comparison with reference floodplains using specific site names, managers and the public have a more tangible perception of possible ecosystem response of future riverine-riparian management strategies.

The future scenario that leads to increased bank stabilization on the Yellowstone River is particularly disconcerting, because this is the type of scenario that is being played out throughout western riparian systems and is the scenario within the current trajectory pattern of interaction between private land-owners and the bank stabilization-permit process that has manifested itself in the Yellowstone River over the past 25 years, and even more so in the past 5 years in response to flooding. Given a continuation of increased bank and floodplain stabilization, it appears that the functional capacity of upper Yellowstone River floodplain/wetland mosaic complexes would be severely compromised.

This projection is consistent with contemporary understanding of fundamentals of floodplain ecology (see issue Freshwater Biology 40(3) 1998 for review), which are incorporated into the logic models and scaling of variables in the HGM Guidebook (Hauer et al., in preparation). The consequences of disconnecting rivers from their floodplains as a result of human alteration of floodplain geomorphology and change in river flow characteristics are becoming well understood (e.g., Sedell and Froggatt (1984), Ward and Stanford (1995), Stanford (1998)). River incisement and armouring as a result of floodplain confinement lead directly to disconnection of habitats and infringement of water flow at both the surface and subsurface. This has a demonstrable, deleterious effect on the ecological function, and therefore integrity, of the river and its associated floodplain aquatic habitats (e.g., springbrooks, wetlands) and riparian plant communities (e.g., cottonwood gallery forest).

Measurement of ecological integrity cannot be expressed as a single indicator, but requires a set of indicators at different spatial, temporal, and hierarchical levels of ecosystem organization (De Leo and Levin 1997). These types of indicators are implicit within the Northern Rocky Mountain riverine HGM guidebook (Hauer et al., in preparation).

Implications of these data to the regulatory program and future planning needs on the upper Yellowstone River are many. Use of the HGM Riverine Guidebook descriptively, in temporal analysis and within a comparative, inter-floodplain reference context has allowed for objective statements on ecosystem status and potential trends. The temporal comparisons of past, present, and potential future condition scenarios necessary for cumulative impact analyses have been demonstrated. Further, the characterization of functional and structural aspects of the ecosystem also provides a conceptual framework for impact assessment and identification of practical consequences stemming from alternative management prescriptions.

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APPENDIX A
LIST OF HGM FUNCTIONS (Hauer et al. 2001) WITH BRIEF DEFINITION. FUNCTIONAL CAPACITY MODELS ARE EXPRESSED AS VARIABLE-BASED ALGORITHMS

Function 1: Surface-Groundwater Storage and Flow

The function Surface-Groundwater Storage and Flow is defined as the capacity of the river, floodplain and associated wetlands to dynamically store and route water primarily under the influence of surface and subsurface flow.

$$FCI = \left[\left(\frac{V_{SURFREQ} + V_{SUBFREQ} + V_{MACRO}}{3}\right) \times V_{GEOMOD}\right]^{1/2}$$

Function 2: Nutrient Cycling

Nutrient cycling is defined by the acquisition of inorganic forms of essential nutrients, converting them into organic forms, generally resulting in plant growth, and then through various microbially-mediated metabolic and biogeochemical processes convert them back into inorganic forms.

$$FCI = \left[\left(\frac{V_{HERB} + V_{SHRUB} + V_{DTREE}}{3}\right) \times V_{COMPLEX} \times V_{ORGDECOMP}\right]^{1/3}$$

Function 3: Retention of Organic and Inorganic Particles

Retention of Organic and Inorganic Particles is defined as the ability of the riverine floodplain-riparian-wetland mosaic to capture and temporarily (e.g., years, decades and centuries) retain both organic and inorganic particles.

$$FCI = \left[\left(\frac{V_{SURFREQ} + V_{MACRO} + V_{COMPLEX} + V_{LWD}}{4}\right) \times V_{GEOMOD}\right]^{1/2}$$

Function 4: Generation and Export of Organic Carbon

The Generation and Export of Organic Carbon is defined as the capacity of a riverine floodplain/wetland complex to generate organic carbon (both dissolved and particulate) through primary production and to export that carbon downstream to other riverine or floodplain habitats and systems.

$$FCI = \left[\left(\frac{V_{SURFREQ} + V_{MACRO}}{2}\right) \times \left(\frac{V_{HERB} + V_{SHRUB} + V_{DTREE}}{3}\right)\right]^{1/2}$$

Function 5: Characteristic Plant Community

Maintaining a Characteristic Plant Community is defined as the capacity of the floodplain-wetland complex to sustain a native plant community that is appropriate for the Reference Domain. Maintaining a plant community characteristic to the floodplains of the region requires vegetative properties such as growth and development of propagules, seed dispersal, density, and growth rates that permit response to natural variation in climate and disturbance (e.g., floods, fire, herbivory). Major change in the relative proportions of vegetative cover and/or invasion by non-native plants and uncharacteristic native species is an indication that this function has been diminished.

$$FCI = \left[\left(\frac{V_{SURFREQ} + V_{SUBFREQ} + V_{MACRO} + V_{COMPLEX}}{4}\right)\right]$$

Function 6: Characteristic Aquatic Invertebrate Food Webs

The function Maintain Characteristic Invertebrate Food Webs is defined as the capacity of the river floodplain to maintain a characteristic diversity and abundance of aquatic invertebrates.

$$FCI = \left[\left(\frac{V_{SURFREQ} + V_{SUBFREQ} + V_{MACRO} + V_{COMPLEX}}{4}\right)\right]$$

Function 7: Characteristic Vertebrate Habitats

The function of maintaining Characteristic Vertebrate Habitats is defined as the capacity of the river floodplain-wetland complex to maintain the habitats necessary for a characteristic diversity and abundance of fish, herptiles (i.e., amphibians and reptiles), birds, and mammals.

$$FCI = \left[\left(\frac{V_{HERB} + V_{SHRUB} + V_{DTREE} + V_{NPCOV}}{4}\right) \times \left(\frac{V_{SURFREQ} + V_{MACRO} + V_{COMPLEX} + V_{HABCON}}{4}\right)\right]^{1/2}$$

Function 8: Floodplain Interspersion and Connectivity

The function of maintaining characteristic Floodplain Interspersion and Connectivity is defined as the maintenance of landscape features of habitat interspersion and connectivity between the river, its floodplain wetlands, and the surrounding floodplain habitats composed of lentic and lotic environments.

$$FCI = \left[\left(\frac{V_{LANDUSE} + V_{HABCON} + V_{COMPLEX}}{3}\right) \times \left(\frac{V_{MACRO} + V_{SURFREQ} + V_{SUBFREQ}}{3}\right) \times V_{GEOMOD}\right]^{1/3}$$

APPENDIX B
NARRATIVE CRITERIA IN SCALING THE VARIABLES V_{GEOMOD}, $V_{COMPLEX}$, V_{HABCON}, AND $V_{LANDUSE}$

Geomorphic Modification (V_{GEOMOD})

This variable represents the anthropogenic modification of the floodplain's geomorphic properties through modifications to control the river channel. Examples of geomorphic modification commonly practiced are riprap, revetment, dikes, levees, bridge approaches, and roadbeds. Each of these human structures function to preclude the movement of water from the channel onto the floodplain.

Calculation table of Variable Subindex Scores based on unaltered and altered geomorphic conditions on the floodplain.

Description	Score
No geomorphic modifications (e.g., dikes, levees, rip-rap, bridge approaches, road beds, etc.) made to contemporary (Holocene) floodplain surface.	1.0
Few changes to the floodplain surface with little impact on flooding. Changes restricted to < 1m in elevation and only for farm roads or bridges with culverts maintained. Geomorphic modifications do however result in minor change in cut-and-fill alluviation.	0.75
Modification to the floodplain surface < 1m in elevation. River bank with control structures (e.g., rip-rap) < 10% of river length along LAA. Geomorphic modifications result in measurable change in cut-and-fill alluviation.	0.5
Multiple geomorphic modifications to the floodplain surface to control flood energy, often with bank control structures, but still permitting flow access via culverts to backwater and side-channels. Geomorphic modifications result in significant reduction in cut-and-fill alluviation.	0.25
Complete geomorphic modification along the river channel of the floodplain surface to control flood energy. Bank control structures in the form of dikes and rip-rap in a continuous structure or constructed to prevent channel avulsion, but still permitting flow access via culverts to backwater and side-channels. Geomorphic modifications result in termination of in cut-and-fill alluviation.	0.1
Complete geomorphic modification along the river channel of the floodplain surface to control flood energy. Bank control structures in the form of dikes and rip-rap in a continuous structure preventing channel avulsion and also preventing flow access via culverts to backwater and side-channels	0

Proportionality of Landscape Features ($V_{COMPLEX}$)

This variable describes the distribution and relative abundance of common cover types that are readily discernible among the majority of alluvial gravel-bed river floodplains in the Northern Rocky Mountains. $V_{COMPLEX}$ is an integral part of the description of landscape quality and the setting of the floodplain wetlands.

Range of percentages of various cover types and the respective Variable Subindex Scores that reflect the Reference Standard condition to a condition that has been significantly impacted with loss of floodplain complexity.

Cover Type	Variable Subindex Score								
	1.0	1.0	0.8	0.7	0.5	0.4	0.2	0.1	0.0
Cover Type 1	10-20%	0-10%	0-10%	>70%	0-10%	0-10%	0-10%	0-10%	0-10%
Cover Type 2	20-40%	30-70%	>70%	0-10%	0-10%	0-10%	0-10%	0-10%	0-10%
Cover Type 3	5-15%	5-10%	0-5%	0-5%	30-60%	0-10%	0-10%	0-10%	0-10%
Cover Type 4	5-15%	5-10%	0-5%	0-5%	20-50%	0-10%	0-10%	0-10%	0-10%
Cover Type 5	5-15%	5-10%	0-5%	0-5%	15-30%	5-15%	0-10%	0-10%	0-10%
Cover Type 6	10-30%	10-30%	0-10%	0-10%	15-30%	>60%	5-40%	5-40%	0-10%
Cover Type 7	5-20%	5-10%	<10%	<10%	<10%	<10%	<10%	<10%	0-10%
Cover Type 8	5-15%	5-15%	<10%	<10%	<15%	<15%	<15%	<15%	<10%
Cover Type 9	2-10%	2-10%	<10%	<10%	<10%	3-6%	3-6%	3-6%	<3%
Cover Type 10	0%	0%	<5%	<10%	10-20%	10-30%	10-30%	10-40%	10-40%
Cover Type 11	0%	0%	<2%	<5%	<5%	<5%	5-10%	10-30%	>40%

Floodplain Habitat Connectivity (V_{HABCON})

This variable describes the connectivity of floodplain habitats between the surface and subsurface, between and among surface wetland features, and between the wetlands and surrounding upland riparian areas.

Habitat connectivity and linear linkages between riparian habitats in the form of movement corridors between cover types, as well as floodplain lentic and lotic habitats and corresponding Variable Subindex Scores.

Description	Score
Cover types 1 – 4 occupy 50 - 80% of area with well-developed connections between patches. Side channels, back and side-channels and floodplain scour pools and ponds well connected to main channel annually. Ponds not connected during base flow, thus permitting isolation for some species. No evidence of floodplain modification either increasing or decreasing connectivity.	1.0
Cover types 1 – 4 occupy 25 - 50% of area with moderately well-developed connections between patches. Occasionally cover type patches 1-3 isolated. Side channels, paleochannels and floodplain scour pools and ponds well connected to main channel 1 in 5 years. Either increased or decreased connectivity due to floodplain modification.	0.8
Cover types 1 – 4 occupy 10- 25% of area with poorly developed connections between patches. At least 50% of cover type patches 1-3 isolated. Side channels, abandoned floodplain channels and floodplain scour pools and ponds connected to main channel only in very high discharge years (1 in 25 to 50 years).	0.6
Cover types 1 – 4 occupy <10% of area with poorly developed connections between patches. Most remaining cover type patches 1-3 are small (<1ha) and isolated. Side channels, , abandoned floodplain channels and floodplain scour pools and ponds never connected to main channel.	0.4
Cover types 1 – 4 occupy <10% of area with poorly developed connections between patches. Most remaining cover type patches 1-3 are small (<1ha) and isolated. Side channels, , abandoned floodplain channels and floodplain scour pools and ponds are never connected and entering later stages of senescence.	0.2
Cover types 1 – 4 occupy <10% replaced by Cover Types 10 and 11 >25% of total area, but less than 50%. Interconnectivity between floodplain wetlands and the main channel greatly reduced.	0.1
Cover types 1 – 4 occupy <10% replaced by Cover Types 10 and 11 >50% of total area. Interconnectivity between floodplain wetlands and the main channel absent.	0

Proportional Landuse ($V_{LANDUSE}$)

This variable is a function of the various land uses and their relative impact on the floodplain. The calculation of this variable is based on the general land use within each Cover Type in the WAA and thus must be evaluated on site.

Calculation table of current landuse and the corresponding Variable Subindex Scores for many of the prevalent landuses encountered on river floodplains across the northern Rocky Mountains.

Current Landuse	Score
Commercial right-of-way, with or without paving, road or parking lot	0.0
Domestic or commercially developed with buildings	0.0
Gravel Pit operation	0.0
Unpaved, private right-of-way (e.g., driveway, tractor trail)	0.1
Tilled Crop Production	0.2
Heavy grazing by livestock	0.3
Logging or tree removal with 75-50% of trees >50cm dbh removed	0.4
Hayed	0.5
Moderate grazing	0.6
Seasonally used for wintering livestock	0.7
Selective logging or tree removal with <50% of trees >50cm dbh removed	0.8
Light grazing	0.9
Fallow with no history of grazing or other human use in past 10yrs	0.95
Wildlands or managed for native vegetation coverage and diversity	1.0

APPENDIX C
VARIABLE SUBINDEX SCORES FOR EACH ASSESSMENT AREA (SEE FIGURE 2) WITHIN THE THREE STUDY RIVER FLOODPLAIN REACHES IN THE UPPER YELLOWSTONE RIVER. DATA ARE PRESENTED FOR EACH OF THE FOUR TEMPORAL CONDITIONS

VARIABLES

Current Condition (2000)

Assessment Area	Vcomplex	Vgeomod	Vhabcon	Vlanduse	Vmacro	Vsubfreq	Vsurfreq	Vorgdecomp	Vdtree	Vshrub	Vherb	Vnpcov	Vlwd
Spring Creek 1	0.90	0.90	0.80	0.30	0.90	1.00	0.66	1.00	0.80	0.57	1.00	0.88	0.75
Spring Creek 2	0.60	0.52	0.70	0.30	0.90	0.92	0.54	0.89	0.64	0.29	0.90	0.63	0.25
Spring Creek 3	0.90	0.39	0.40	0.65	0.90	0.84	0.54	1.00	0.86	0.35	1.00	0.57	0.75
Spring Creek 4	0.40	0.38	0.70	0.30	0.90	0.87	0.35	0.90	0.35	0.55	1.00	0.76	0.25
Mallards Rest 1	0.95	1.00	1.00	0.25	0.60	1.00	1.00	0.97	0.70	0.16	0.27	0.47	0.30
Mallards Rest 2	0.50	1.00	0.60	0.16	0.80	0.85	0.60	1.00	0.84	0.10	0.88	0.14	0.50
Emigrant 1	0.90	0.61	0.50	0.59	0.90	0.75	0.59	0.90	0.93	0.84	0.60	0.41	0.75
Emigrant 2	0.80	0.84	0.80	0.75	1.00	1.00	0.93	1.00	0.75	0.27	0.99	0.51	1.00
Emigrant 3	0.70	0.98	0.50	0.97	0.90	0.98	0.86	0.95	0.90	0.42	0.70	0.48	0.75

Backcast Condition (1976)

Assessment Area	Vcomplex	Vgeomod	Vhabcon	Vlanduse	Vmacro	Vsubfreq	Vsurfreq	Vorgdecomp	Vdtree	Vshrub	Vherb	Vnpcov	Vlwd
Spring Creek 1	0.90	0.90	0.80	0.30	0.90	1.00	0.82	1.00	0.80	0.80	1.00	0.88	0.75
Spring Creek 2	0.90	0.99	0.70	0.44	0.90	0.92	0.54	1.00	0.64	0.32	0.90	0.63	0.25
Spring Creek 3	0.90	0.84	0.80	0.87	0.90	0.84	0.94	1.00	0.86	0.79	1.00	0.57	0.75
Spring Creek 4	0.80	0.79	0.70	0.30	0.90	0.87	0.35	0.90	0.35	0.55	1.00	0.76	0.25
Mallards Rest 1	0.95	1.00	1.00	0.25	0.60	1.00	1.00	0.97	0.70	0.16	0.27	0.47	0.30
Mallards Rest 2	0.50	1.00	0.60	0.16	0.80	0.85	0.60	1.00	0.84	0.10	0.88	0.14	0.50
Emigrant 1	0.90	0.61	0.80	0.59	0.90	0.75	0.60	0.90	0.93	0.84	0.60	0.41	0.75
Emigrant 2	0.80	0.84	0.80	0.90	1.00	1.00	0.93	1.00	0.75	0.81	0.99	0.76	1.00
Emigrant 3	0.80	0.98	0.70	0.99	0.90	0.98	0.86	0.95	0.90	0.42	0.70	0.48	0.75

Forecast-confined

Assessment Area	Vcomplex	Vgeomod	Vhabcon	Vlanduse	Vmacro	Vsubfreq	Vsurfreq	Vorgdecomp	Vdtree	Vshrub	Vherb	Vnpcov	Vlwd
Spring Creek 1	0.90	0.90	0.80	0.90	0.90	1.00	0.66	1.00	0.80	0.76	1.00	0.88	0.75
Spring Creek 2	0.90	0.90	0.80	0.90	0.90	0.92	0.81	0.89	0.64	0.29	0.90	0.66	0.70
Spring Creek 3	0.90	0.90	0.50	0.94	0.90	0.84	0.88	1.00	0.86	0.71	1.00	0.70	0.75
Spring Creek 4	0.80	0.90	0.70	0.90	0.90	0.87	0.90	0.90	0.35	0.90	1.00	0.76	0.70
Mallards Rest 1	0.95	1.00	1.00	0.90	0.80	1.00	1.00	0.97	0.70	0.85	0.80	0.70	0.70
Mallards Rest 2	0.50	1.00	0.60	0.16	0.80	0.85	0.60	1.00	0.84	0.10	0.88	0.14	0.70
Emigrant 1	0.90	0.67	0.80	0.90	0.90	0.75	0.59	0.90	0.93	0.84	0.60	0.71	0.75
Emigrant 2	0.80	0.84	0.80	0.90	1.00	1.00	0.93	1.00	0.75	0.27	0.99	0.76	1.00
Emigrant 3	0.70	0.98	0.50	0.99	0.90	0.98	0.86	0.95	0.90	0.42	0.70	0.48	0.75

Forecast-unconfined

Assessment Area	Vcomplex	Vgeomod	Vhabcon	Vlanduse	Vmacro	Vsubfreq	Vsurfreq	Vorgdecomp	Vdtree	Vshrub	Vherb	Vnpcov	Vlwd
Spring Creek 1	0.40	0.18	0.10	0.20	0.60	0.55	0.44	1.00	0.50	0.41	0.51	0.50	0.20
Spring Creek 2	0.40	0.19	0.10	0.20	0.80	0.32	0.16	0.89	0.46	0.28	0.50	0.48	0.20
Spring Creek 3	0.40	0.39	0.10	0.42	0.60	0.41	0.26	1.00	0.46	0.30	0.48	0.47	0.20
Spring Creek 4	0.40	0.38	0.10	0.20	0.80	0.57	0.23	0.90	0.35	0.25	1.00	0.46	0.20
Mallards Rest 1	0.40	0.25	0.40	0.20	0.20	1.00	0.49	0.97	0.70	0.16	0.27	0.47	0.20
Mallards Rest 2	0.50	0.25	0.40	0.16	0.80	0.58	0.22	1.00	0.84	0.10	0.88	0.14	0.20
Emigrant 1	0.40	0.25	0.20	0.41	0.40	0.75	0.48	0.90	0.76	0.84	0.60	0.41	0.20
Emigrant 2	0.40	0.10	0.40	0.20	1.00	0.63	0.66	1.00	0.75	0.27	0.99	0.51	0.20
Emigrant 3	0.50	0.71	0.50	0.94	0.90	0.95	0.91	0.71	0.54	0.55	0.70	0.69	0.20

APPENDIX D
FUNCTIONAL CAPACITY INDEX SCORES FOR EACH ASSESSMENT AREA (see Figure 2) WITHIN THE THREE STUDY RIVER FLOODPLAIN REACHES IN THE UPPER YELLOWSTONE RIVER. DATA ARE PRESENTED FOR EACH OF THE FOUR TEMPORAL CONDITIONS

Current Condition (2000)	FUNCTIONS							
Assessment Area	F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-8
Spring Creek 1	0.88	0.89	0.85	0.79	0.85	0.86	0.81	0.80
Spring Creek 2	0.64	0.69	0.54	0.66	0.62	0.74	0.65	0.60
Spring Creek 3	0.54	0.87	0.55	0.73	0.66	0.80	0.69	0.58
Spring Creek 4	0.52	0.61	0.42	0.63	0.66	0.63	0.62	0.50
Mallards Rest 1	0.93	0.70	0.84	0.55	0.49	0.89	0.60	0.86
Mallards Rest 2	0.87	0.67	0.78	0.65	0.29	0.69	0.55	0.68
Emigrant 1	0.67	0.86	0.69	0.77	0.58	0.78	0.71	0.67
Emigrant 2	0.91	0.81	0.89	0.80	0.60	0.93	0.74	0.86
Emigrant 3	0.95	0.76	0.89	0.77	0.57	0.86	0.68	0.87
Backcast Condition (1976)								
Assessment Area	F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-8
Spring Creek 1	0.90	0.92	0.87	0.86	0.88	0.90	0.86	0.82
Spring Creek 2	0.88	0.82	0.80	0.67	0.66	0.81	0.69	0.81
Spring Creek 3	0.86	0.93	0.85	0.90	0.71	0.89	0.84	0.86
Spring Creek 4	0.75	0.77	0.67	0.63	0.71	0.73	0.68	0.69
Mallards Rest 1	0.93	0.70	0.84	0.55	0.49	0.89	0.60	0.86
Mallards Rest 2	0.87	0.67	0.78	0.65	0.29	0.69	0.55	0.68
Emigrant 1	0.67	0.86	0.69	0.77	0.58	0.79	0.75	0.70
Emigrant 2	0.91	0.88	0.89	0.90	0.80	0.93	0.85	0.88
Emigrant 3	0.95	0.80	0.90	0.77	0.58	0.89	0.71	0.91
Forecast-confined								
Assessment Area	F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-8
Spring Creek 1	0.88	0.92	0.85	0.81	0.87	0.86	0.84	0.87
Spring Creek 2	0.89	0.79	0.86	0.72	0.67	0.88	0.73	0.88
Spring Creek 3	0.89	0.92	0.88	0.87	0.78	0.88	0.81	0.85
Spring Creek 4	0.90	0.81	0.86	0.82	0.76	0.87	0.79	0.86
Mallards Rest 1	0.97	0.90	0.93	0.84	0.76	0.94	0.85	0.96
Mallards Rest 2	0.87	0.67	0.81	0.65	0.29	0.69	0.55	0.68
Emigrant 1	0.71	0.86	0.72	0.77	0.76	0.78	0.78	0.76
Emigrant 2	0.91	0.81	0.89	0.80	0.73	0.93	0.78	0.88
Emigrant 3	0.95	0.76	0.89	0.77	0.57	0.86	0.68	0.87
Forecast-unconfined								
Assessment Area	F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-8
Spring Creek 1	0.31	0.57	0.27	0.50	0.48	0.50	0.43	0.28
Spring Creek 2	0.28	0.53	0.27	0.45	0.44	0.42	0.40	0.26
Spring Creek 3	0.40	0.55	0.37	0.42	0.44	0.42	0.38	0.37
Spring Creek 4	0.45	0.58	0.39	0.53	0.48	0.50	0.44	0.36
Mallards Rest 1	0.38	0.53	0.28	0.36	0.42	0.52	0.39	0.36
Mallards Rest 2	0.36	0.67	0.33	0.55	0.29	0.52	0.48	0.36
Emigrant 1	0.37	0.64	0.30	0.57	0.52	0.51	0.49	0.36
Emigrant 2	0.28	0.64	0.24	0.74	0.55	0.67	0.62	0.30
Emigrant 3	0.81	0.61	0.65	0.73	0.51	0.79	0.61	0.72